HIERARCHY EFFECTS IN LIGHT FRAGMENTS AT MID-VELOCITY EMISSION

F. Amorini[a,b], A. Anzalone[a], L. Auditore[c], V. Baran[d], I. Berceanu[e], J. Blicharska[f], B. Borderie[g], R. Bougault[h], M. Bruno[i], J. Brzychczyk[j], G. Cardella[k], S. Cavallaro[a,b], M.B. Chatterjee[l], A. Chbihi[m], M. Colonna[a], M. D'Agostino[i], R. Dayras[n], E. De Filippo[k]*, M. Di Toro[a,b], J. Frankland[h], E. Galichet[g], W. Gawlikowicz[j], E. Geraci[b,k], F. Giustolisi[a,b], L. Grassi[a,k], A. Grzeszczuk[f], P. Guazzoni[o], D. Guinet[p], S. Kowalski[f], E. La Guidara[q], G. Lanzalone[a,r], G. Lanzanò[k], N. Le Neindre[h], I. Lombardo[a,b], C. Maiolino[a], Z. Majka[j], A. Pagano[k], M. Papa[k], M. Petrovici[e], E. Piasecki[s,t], S. Pirrone[k], R. Płaneta[j], G. Politi[b,k], A. Pop[e], F. Porto[a,b], M.F. Rivet[g], F. Rizzo[a,b], E. Rosato[u], , P. Russotto[a,b], K. Schmidt[j], K. Siwek-Wilczyńska[v], I. Skwira[v], A. Trifirò[c], M. Trimarchi[c], G. Verde[k], M. Vigilante[u], J.P. Wieleczko[m], J. Wilczyński[t], L. Zetta[o] and W. Zipper[f]

a) INFN, Laboratori Nazionali del Sud, Catania, Italy
b) Dipartimento di Fisica e Astronomia, Univ. di Catania, Catania, Italy
c) INFN, Gr. Coll. di Messina and Dip. di Fisica, Univ. di Messina, Italy
d) University of Bucharest and IFIN-HH, Bucharest, Romania
e) National Institute of Physics and Nuclear Engineering "Horia Hulubei", Bucharest, Romania
f) Institute of Physics, University of Silesia, Katowice, Poland
g) Institut de Physique Nucléaire, CNRS/IN2P3, Université Paris-Sud 11, Orsay, France
h) LPC Caen, ENSICAEN, University of Caen, CNRS/IN2P3, Caen France
i) INFN, Sezione di Bologna and Dipartimento di Fisica, Univ. di Bologna, Italy
j) M.Smoluchowski Institute of Physics, Jagellonian Univ., Cracow, Poland
k) INFN, Sezione di Catania, Catania, Italy
l) Saha Institute of Nuclear Physics, Kolkata, India
m) GANIL (DSM-CEA/CNRS/IN2P3), Caen, France
n) DAPNIA/SPhN, CEA-Saclay, France
o) INFN, Sezione di Milano and Dipartimento di Fisica, Univ. di Milano, Italy
p) Institut de Physique Nucléaire, CNRS/IN2P3, Université Claude-Bernard Lyon I, Lyon, France
q) CSFNSM, Catania ,Italy
r) Università "Kore", Enna, Italy
s) Heavy Ion Laboratory, University of Warsaw, Warsaw, Poland
t) A.Soltan Institute for Nuclear Studies, Swierk/Warsaw, Poland
u) INFN, Sezione di Napoli and Dipartimento di Fisica, Univ. di Napoli, Italy
v) Institute of Experimental Physics, University of Warsaw, Poland

**corresponding author, e-mail*: defilippo@ct.infn.it

Abstract

Intermediate mass fragments (IMF) emitted with multiplicity $M_{IMF} \geq 3$ at mid-velocity in semi-central reactions induced by ^{124}Sn projectile (35 A.MeV) on ^{64}Ni target have been studied. The results show a clear correlation between the fragment sizes and the corresponding transverse velocities. We interpret this correlation as signature of hierarchy effects in nuclear multifragmentation. A correlation with the fragments isospin contents is also found. Qualitative comparisons with SMF calculations suggests that these correlations are good observables for the symmetry term of the EOS at sub-saturation density.

INTRODUCTION

In the study of the reactions ^{124}Sn+^{64}Ni and ^{112}Sn+^{58}Ni with the Chimera detector, the time-scale for fragments formation has been recently investigated [1], in order to disentangle between prompt dynamical and sequential statistical emission. In semi-peripheral reactions prompt emitted light particles (Z≤9) are mainly originated by the fragmentation of the neck in a short time within 40-80 fm/c after the re-separation of the two main partners PLF (projectile-like) and

TLF (target-like) of the reaction. Dynamical IMFs emission is characterized by larger N/Z ratio and angular anisotropies respect to particles produced in sequential statistical emission [2]. Fast emission of heavier fragments ($Z \geq 10$) happens generally at later stage of the neck fragmentation process. Recently [3] has been shown that this last process can be interpreted in the framework of the so-called "dynamical fission" of a projectile-like fragment. The aim of this report is to study the transition between peripheral and central collisions in dissipative process. When going towards more central collisions, progressively a multifragmentation decay with higher IMFs multiplicity takes place with respect to the peripheral collision where the coexistence of prompt emission and sequential decay was observed [4]. In order to better explore this transition region we have analysed semi-central collisions in the $^{124}Sn+^{64}Ni$ reaction looking at events in which together with a PLF and TLF residue fragments a further multiplicity $M \geq 3$ of light IMFs are present.

RESULTS

For the class of events in which the total charge Z_{TOT} and the total parallel momentum are respectively greater than 70% of the total charge and projectile momentum of the colliding nuclei we have considered three different bins of the total charged particle multiplicity *M*, going from semi-peripheral reactions ($M \leq 6$, $b/b_{max} > 0.7$), to the most dissipative collisions ($M > 12$, $b/b_{max} < 0.1$). For the intermediate total multiplicity bin $7 \leq M \leq 12$ we have analysed the class of events in which after selection of PLF and TLF residue fragments, a multiplicity $M \geq 3$ of IMFs are present (thus, for the selected events total IMF multiplicty is $M_{IMF} \geq 5$). For these fragments, in the c.m. system, the parallel and the transverse velocity components respect to the separation axis $V_{PLF} - V_{TLF}$ vector have been evaluated. The parallel and the transverse velocity of the IMFs were evaluated event by event and, thus ordered according to their size. Fig 1 shows the parallel a) and transverse velocities b) distributions. The result shows a clear tendency to some "hierarchy" effect in the transverse velocity distribution: the greatest transverse velocity is reached by the lightest fragments. In contrast, a such effect is not evidenced for the parallel velocity distribution.

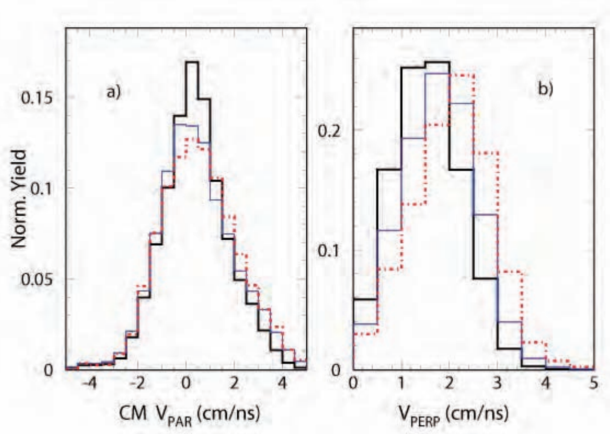

Fig. 1: a) Parallel velocity distributions for events with 3 IMFs sorted as a function of fragment charge. Black thick line (biggest charge), thin blue line (intermediate), red dot-dashed (smallest charge); b) the same for the IMFs transverse velocity.

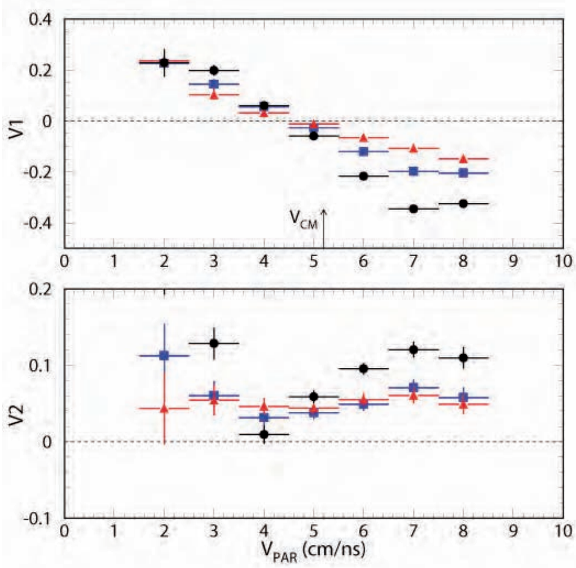

Fig. 2: Transverse flow V_1 a) and elliptic flow V_2 b) as a function of the parallel velocity for fragments ordered in a rank based on charge: biggest fragment (circle), intermediate fragment (squares), smallest fragments (triangles).

In order to get more insight into this "hierarchy" effect we have constructed, for the selected events, the IMFs azimuthal angular distributions respect to the reaction plane defined as the normal vector to the plane defined by $n=(V_S \times V_{CM})$ where $V_S = V_{PLF}-V_{TLF}$ and V_{CM} is the beam velocity direction in the center of mass reference system.

Flow observables are obtained from the Fourier expansion of the azimuthal distributions:

$$dN/d\varphi = 1 + V_1\cos(\varphi) + 2V_2\cos(2\varphi)$$

where V_1 and V_2 are the transverse and elliptic flow respectively. V_1 gives indication of the azimuthal anisotropy in the reaction plane. Fig 2a) shows V_1 as a function of laboratory parallel velocity respectively for the biggest fragment (black circle), the intermediate one (blue square) and the smallest one (red triangle). The largest slopes for V_1 are reached by the biggest fragment indicating the tendency for emission in the reaction plane in an aligned configuration with PLF or TLF. The slope becomes less steeper following the rank in the charge hierarchy. This behaviour is confirmed in fig. 2b) where V_2 is shown for the same particles as a function of laboratory parallel velocity. A positive V_2 values indicates a preferential emission in the reaction plane. We note also a tendency for the lightest particles in the rank to have a flat distribution, probably indicating the competition of different reaction mechanisms in their formation.

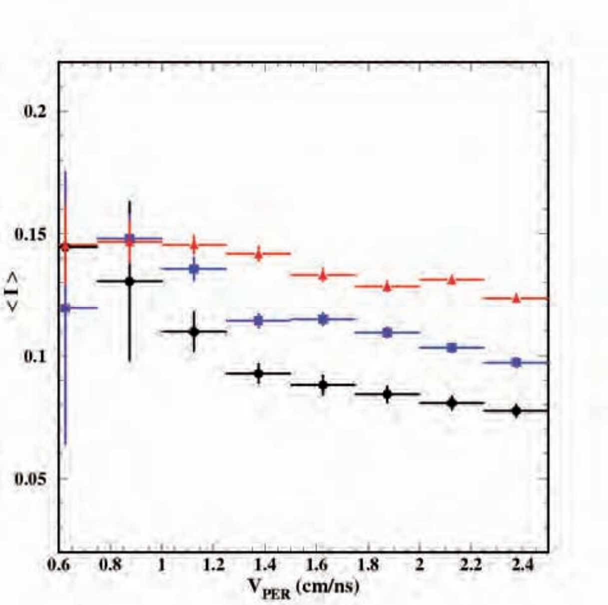

Fig. 3: Isospin asymmetry (N-Z)/A as a function of the transverse velocity. Biggest fragment (circle), intermediate fragment (squares), smallest fragments (triangles).

Fig. 3 shows the isospin asymmetry distribution as a function of the transverse velocity for the biggest fragment (black circle), the intermediate one (blue square) and the smallest one (red triangle) in the charge rank. We note the tendency for the isospin asymmetry to lowering at increasing of the transverse velocity. For all transverse velocities the lighter fragments have always the largest asymmetry.

It is interesting to compare the experimental data with the results of SMF [5] simulations, performed for neutron rich and neutron poor Sn+Sn symmetric reactions at 50 A.MeV [6]. In these simulations a similar hierarchy effect in transverse velocity is shown and interpreted as an interplay between neck fragmentation and the onset of the multifragmentation. The calculations show a sensitivity to the choice of different symmetry term behaviour in the nuclear EOS. For example, in the calculation for a soft symmetry term of the EOS no difference in the isospin content of the fragments is found as a function of the rank hierarchy. In contrast, a stiffer symmetry term EOS produces a marked difference: the asymmetry increases following the rank in hierarchy.

The preliminary experimental results shown here indicate a first evidence of a correlation between the fragments isospin contents and the transverse velocity suggesting a valuable input for future analysis for studying the symmetry term of the EOS.

REFERENCES

[1] E. De Filippo et al., Phys. Rev C71, 044602 (2005)

[2] E. de Filippo et al., Acta Phys. Polonica B40, 1199 (2009).

[3] P. Russotto et al., in press Phys. Rev. C (2010).

[4] P. Russotto et al., Proceedings of the INPC 2007 conference (Tokio, June 3-8 2007), Vol II, pp 507 (2008); E. De Filippo et al., proc. IWM 2009 (in press).

[5] V. Baran et al., Nucl. Phys. A730, 329 (2004).

[6] V. Baran et al., Proceedings of the IWM International Workshop on Multifragmentation (in press, 2010).